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SMR.1221 - 6

SPRING WORKSHOP ON SUPERSTRINGS AND RELATED MATTERS

27 March - 4 April 2000

SOME ASPECTS OF LIFE ON A BRANE

Lectures I and II

C. BACHAS
Ecole Normale Superieure
Lab. de Physique Theorique
Paris 75231
FRANCE

C. Bachas

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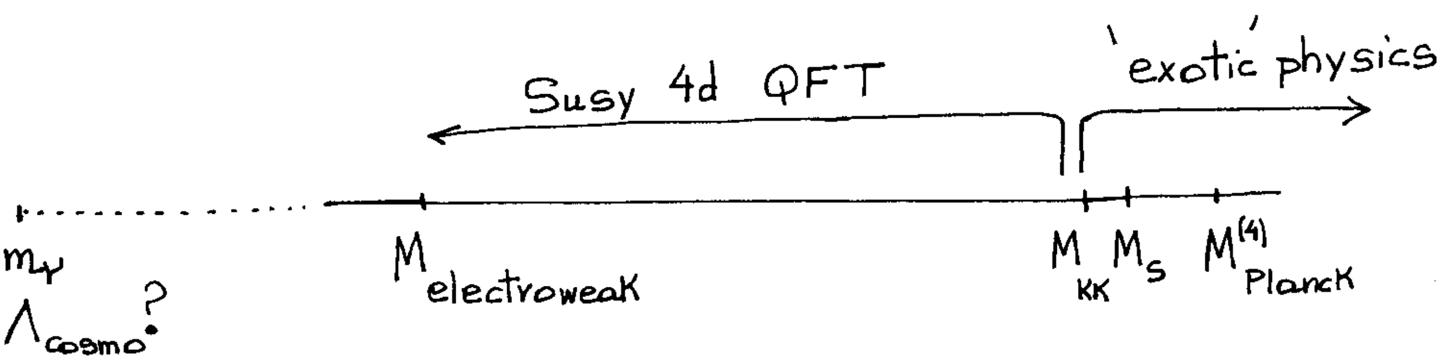
Some aspects of life on a brane

① Scales of string theory

cf. C.B, hep-th/0001093
& references therein

String/M-theory: single dimensionful parameter ($M^{(11)}_{Planck}$ or M_s) and large # of dynamical moduli

Conventional hypothesis:



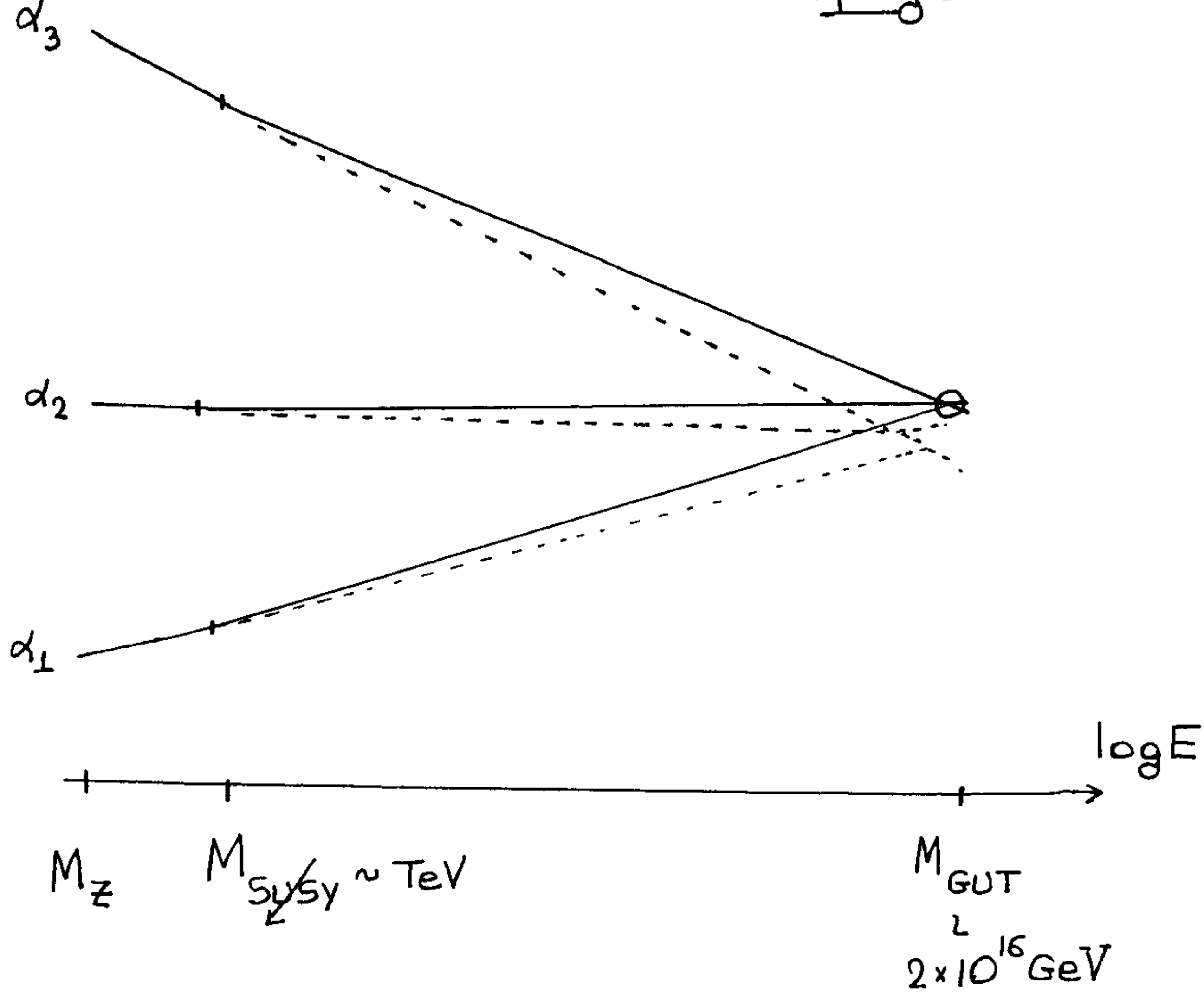
3 reasons in support:

↳ SQFT (MSSM) <u>can</u> be extrapolated to $\lesssim M^{(4)}_{Planck}$

↳ (susy) gauge coupling unification

↳ automatic in (weakly-coupled) heterotic string

Unification of gauge <u>couplings</u>



minimal desert hypothesis:

<u>one</u> prediction better than ~few %

\

$$\frac{1}{\alpha(\mu)} = \frac{1}{\alpha_{GUT}} + \underbrace{b_i}_{\substack{\text{MSSM}\\ \beta\text{-functions}}} \log \mu/M_{GUT} + \underbrace{\Delta_i}_{\substack{\text{GUT `thresholds'}\\ \text{susy `thresholds'}}}$$

thresholds $\sim \log \mu/M_{susy}$ or $\log M_{heavy}/M_{GUT}$

$\sim$ few % corrections to $\delta\alpha^{-1}(\mu)$, because of huge UV desert!

In weakly-coupled heterotic string unification is expected at string scale (M_h)

and

$$M_h^2 \sim M_{Planck}^2 \cdot \alpha_{GUT}$$
$$= (5 \times 10^{17}\ GeV)^2 \qquad \text{(Kaplunovsky)}$$

on log-scale second successful prediction good to within few %. Prediction would hold (to within this accuracy) whenever

$$`\ \tfrac{1}{10} \lesssim \langle \text{moduli} \rangle \lesssim 10\ '$$

more generally

* existence of M_{GUT} indirectly in agreement with τ_{proton}, m_ν

Weakly-coupled heterotic string

graviton
gauge bosons } live in 10d bulk

(5-brane non-perturbative cf. Benakli-Oz)

$$\therefore \quad \mathcal{L}_{YM} \sim \underbrace{\frac{(rM_h)^6}{g_h^2}}_{\downarrow \; \frac{1}{\alpha_{GUT}}} \mathrm{tr}\, F^2 \qquad \mathcal{L}_{Einstein} \sim \underbrace{\frac{r^6 M_h^8}{g_h^2}}_{\downarrow \; M^2_{Planck}} R$$

$$\therefore \quad \boxed{\begin{aligned} M_h^2 &\sim M^2_{Planck} \cdot \alpha_{GUT} \\ \alpha_{GUT} &\sim g_h^2 / (rM_h)^6 \end{aligned}}$$

weak coupling $\rightarrow$ $g_h \lesssim 1$

T-duality $\rightarrow$ $rM_h \gtrsim 1$

If $\alpha_{GUT} \sim o(1/20)$ (not much much smaller)

then M_{Planck}, M_h, $M_{KK} \sim \frac{1}{r}$

all within a couple of orders of magnitude!

<u>NB</u> Can $\alpha_{GUT} \ll 1$?

a priori yes, but need to drive $\alpha_i \to o(1)$
need huge thresholds (extra dims ?)
but this means loss of calculability in
gauge sector.

Susy breaking

in perturbnt. theory $m_{susy} \longrightarrow 0$ is
decompactificnt limit:

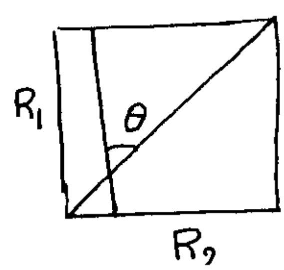
↳ 'Scherk-Schwarz'

$$P = \begin{cases} n/R & \text{bosons} \\ \frac{n+1/2}{R} & \text{fermions} \end{cases} \qquad \text{(like finite } T\text{)}$$

$$\Rightarrow m_{susy} \sim \frac{1}{2R}$$

↳ 'Magnetic' (brane rotn)

$$m = 2 \cdot Q_R \cdot \frac{\theta}{\pi} + \text{universal}$$



$$\therefore\ m_{susy} \simeq \arctan \frac{R_2}{R_1} \simeq \frac{R_2}{R_1} \simeq \frac{1}{R_1 \tilde{R}_2}$$

if small — after T-duality in direction 2

note: space-filling crucial since otherwise can construct near-extremal BHs $\leftarrow$ anomalies

$$\simeq \frac{1}{\widetilde{\text{Area}}} \qquad (\ell_s = 1)$$

↳ Fayet-Iliopoulos

$$m_{susy} \sim \mathrm{tr}\,Q^2 \sim o(1) \quad \text{in string units}$$

General theorem (Banks + Dixon) that susy restauration is singular limit! $\left\{ \begin{array}{l} \text{no marginal} \\ \text{operator to} \\ \text{break } N=2 \to N \end{array} \right.$

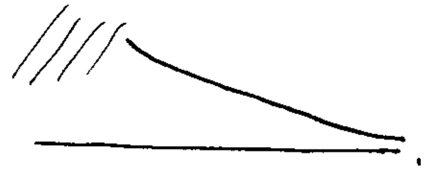
So in weakly-coupled heterotic string only real 'option' is non-perturbative (gaugino condensation)?

$$m_{susy} \sim e^{-\#/g_h^2} \ll M_h$$

vacuum stability?

Λ_{cosmo}, dilaton runaway

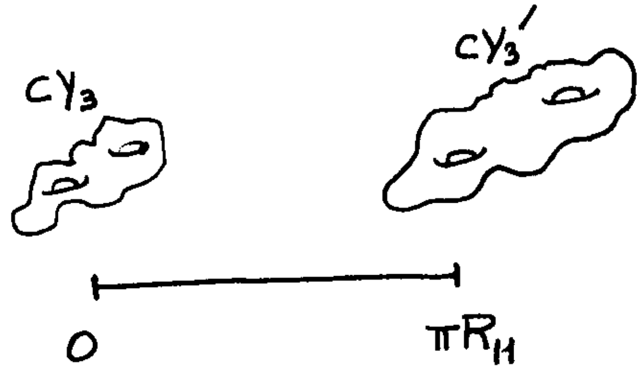
V



Brane Worlds

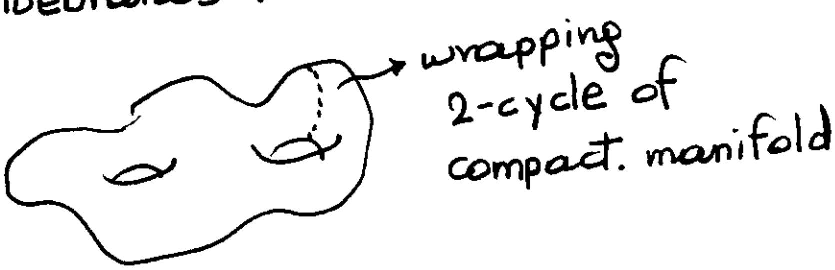
made possible by realization that branes can trap spin-1 (gauge) fields in their worldvolumes:

ex strongly-coupled heterotic string:

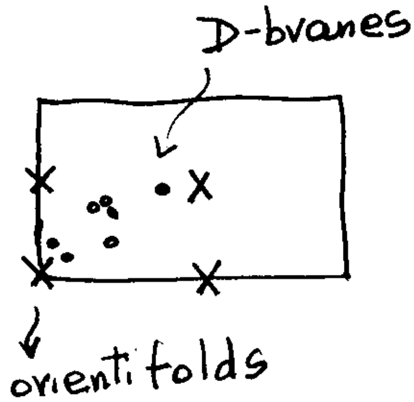


Horava-Witten

heterotic fivebranes:



type I (A or B) theory:



perturbative string theoretic description

In all these instances gravitons & gauge bosons live in different spaces

$\Rightarrow$ universal relnt between

M_{Planck}, M_s, α_{GUT} lost.

Consider eg type I theory:

$$\mathcal{L}_{YM} \sim \frac{(r_{\parallel} M_I)^{6-n}}{g_I} \operatorname{tr} F^2$$

confined on D-branes with n transverse dims

$$\mathcal{L}_{Einstein} \sim \frac{r_{\parallel}^{6-n}\, r_{\perp}^{n}\, M_I^{8}}{g_I^2} \mathcal{R}$$

$$\therefore \quad M_{Planck}^2 \sim M_I^2 \cdot \alpha_{GUT}^{-1} \cdot \boxed{\frac{(r_{\perp} M_I)^n}{g_I}}$$

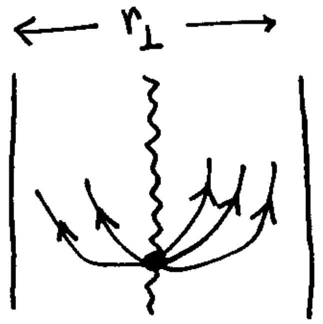
extra moduli-dependence

Keeping all other dimensionless params of $o(1)$, can lower M_I by tuning $(r_{\perp} M_I)$ up.

Less predictive than heterotic string, but part of (controllable) moduli space of $\mathcal{M}$-theory, so should consider.

Experimental bounds

↳ Mesoscopic gravity



weakness of 4d gravity due to transverse spreading of gravitnl flux

bound $r_\perp \lesssim$ mm

ArKani-Hammed, Dimopoulos, Dvali

(cf Moody, Wilczek
Kuzmin, Tkachev, Shaposhnikov
grav. axions

two types of expmt:

Cavendish (measure $1/r^2$)

Casimir force (measure r-dependence const. for Newton's law)

Basic limitation:

residual electromagnetic interactions

<u>ex</u> $$\frac{F_{VdW}}{F_{Newton}} \sim \left(\frac{1mm}{d}\right)^5$$ for two H-atoms

limits could be pushed one to two orders of magnitude in near future

↳ Precision <u>tests of</u> SM

hard to exclude any new physics, in model-independent way, above TeV (so $M_s, r_{\parallel}^{-1} \gtrsim$ TeV)

<u>ex</u> g-2 factor of electron

dim-5 operator $\sim \frac{m_e}{\Lambda^2} \bar{\Psi} \gamma^{\mu\nu} F_{\mu\nu} \Psi$

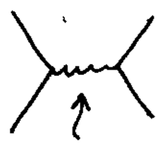
↑ because it violates chiral symmet

$$\therefore \frac{\delta(g-2)}{g-2} \sim \left(\frac{m_e}{\Lambda}\right)^2 \frac{1}{\alpha} \sim 10^{-10} \ll 10^{-8}$$

experimental limit

↳ Exotic processes

eg proton decay



X,Y bosons

in conventional Unification suppressed by heavy M_X, M_Y (just barely ?)

here large scale is infrared, use it:

$U(1)_B$ gauged in bulk (almost global) broken at some distant brane, to save equivalence principle (no spin-1 long-range interaction)

Shiu Tye

Similarly for small m_ν

eg emission of gravitons in bulk (missing energy)

$$\mathcal{L}_{brane} = \int d^{4+n}x \left\{ \partial_\mu \varphi(x_\parallel) \partial_\nu \varphi(x_\parallel) G^{\mu\nu}(x_\parallel, x_\perp) \delta^{(n)}(x_\perp) \right.$$

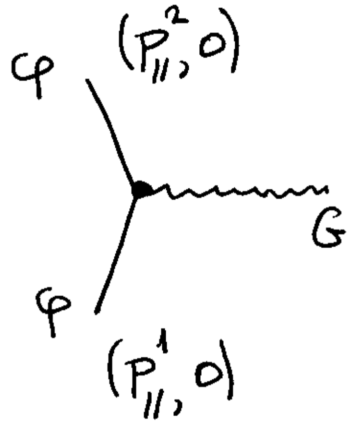
SM fields localized on brane

$+ \ldots\ldots$

$$\delta^{(n)} \to e^{-x_\perp^2/2\rho^2}$$

(form-factor for 'brane thickness' ρ)

In momentum space:

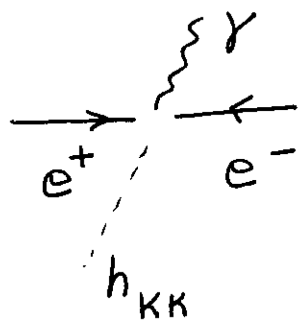


$$(p_\parallel^3, p_\perp) \approx \delta^{(4)}(p_\parallel^1 + p_\parallel^2 + p_\parallel^3) \cdot e^{-p_\perp^2 \rho^2 / \ldots}$$

i.e. transverse momentum not conserved

momentum violation cutoff at $\sim 1/\rho \sim M_I$ for type-I D-branes

ex



$$\text{(inclusive) cross-section} \sim \frac{1}{M_{Pl}^2} * (r_\perp E_{CM})^n$$

$\uparrow$ # of available KK states 'cancels' weakness of grav. coupling

$$\sim \frac{1}{M_s^2} \left(E_{CM}/M_s \right)^n$$

$\therefore$ process appreciable at $E_{CM} \sim M_s$ (details depend on ρ etc).

Conclusions

↳ $M_s \neq \sim \frac{1}{10} M_{Planck}$ possible
part of $\mathcal{M}$-theory moduli space

↳ $M_s, r_{\parallel}^{-1} \gtrsim$ TeV
$r_{\perp} \gtrsim$ mm
consistent with experimental bounds

↳ 'Classical' low-E susy breaking possible, does not yet 'improve' stability problems

↳ Unification ?
<u>two</u> predictions good at few %.